EVALUATION OF WASTE CRUSHED ROCK FOR USE IN CONCRETE RAILROAD TIES

(UP-L-276)

Final Report

by

N.G.Zoldners, Eng.

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A B S T R A C T

The petrographic examination of both rock and sand samples has not indicated that any alkali reactive minerals are present in the aggregates under investigation.

The results of the chemical tests show that both the rock and sand samples may be considered as innocuous material.

Mortar bar tests using crushed rock and high-alkali cement show a maximum initial shrinkage of - 0.009% at 1 month, which reversed to a net expansion of + 0.007% at 9 months. For mortar bars made with low-alkali cement the shrinkage was much larger and the corresponding measurements were - 0.016% and - 0.007%, with no net expansion observed.

Concrete prism tests showed even greater shrinkage, with the maximum of initial shrinkage for all three sets of prisms reaching about - o.023% after 84 days of moist curing, or more than double that observed on mortar bars. It reduced to about - 0.020% at 112 days and stayed at that level for the rest of the year. Expansion of prisms within 1 year was so low that it compensated little for the shrinkage that occured during the initial 84-day period.

These tests indicate that the waste rock and mill tailing sand from Hilton Mines are not deleteriously reactive with the alkalies in portland cement concrete within one year's time.

RESUMÉ

L'examen pétrographique des échantillons de pierre et de sable n'a pas indiqué la présence de minéraux réactifs aux alcalis dans les granulats étudiés.

Les résultats des essais chimiques démontrent que les échantillons de pierre aussi bien que ceux de sable peuvent être considérés comme des matériaux inoffensifs.

Les essais sur barres de mortier contenant de la pierre broyée et du ciment à haute teneur en alcalis indiquent un retrait initial maximum de -0.009% à 1 mois, lequel change en une dilatation nette de +0.007% à 9 mois. Pour les barres de mortier fabriquées avec du ciment à basse teneur en alcalis, le retrait fut beaucoup plus grand et les valeurs correspondantes furent de -0.016% et -0.007% avec aucune dilatation nette observée.

Les essais sur prismes de béton ont démontré un retrait encore plus grand avec une valeur maximum pour les trois séries de prismes atteignant près de -0.023% après 84 jours, c'est-à-dire plus que le double de celui observé sur les barres de mortier. Cette valeur est descendue à environ -0.020% à 112 jours pour demeurer à ce niveau jusqu'à une période de 1 an. La dilatation des prismes à l'intérieur de cette dernière période fut tellement peu prononcée qu'elle n'a pu compenser pour le retrait qui avait eu lieu pendant la période initiale de 84 jours.

En général, les essais indiquent que la pierre de rejet et le sable résiduel d'usine de traitement des Mines Hilton sont exempts de réactivité nocive avec les alkalis du ciment portland à l'intérieur de la période étudiée, c'est-à-dire une période de 1 an.

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INTRODUCTION

Until recent years, it has been the practice to consider concrete aggregate as inert material. However, experience with deteriorating concrete structures is demonstrating that many aggregates, far from being inert, are chemically and physically active and exert a critical control on concrete durability and serviceability.

Thus concrete with normally acceptable aggregate after several years of satisfactory service, when subjected to frequent wetting, extended exposure to humid atmosphere, or contact with moist ground, may show signs of progressive deterioration.

Research in the last 30 years has revealed that a form of concrete deterioration found in several regions in Canada resulted from a reaction between the alkalis in cement and certain chemically active minerals in somerock types. Such reaction may produce excessive expansion of concrete, which ultimately may cause immense damage and structural failures. In the Montreal area several hydro-electric dams, bridge piers and other concrete structures have deteriorated beyond repair and must be demolished and replaced.

An additional concern is the decreasing availability of suitable aggregates, particularly near major centers of use. Possible sources of acceptable aggregates are mining waste dumps all of which should be evaluated because production cost from them could be low. One such dump in Ottawa area is the tremendous 75 million ton pile of crushed granitic waste rock left at the closed

Hilton Iron Mines, at Shawville, Québec. This material is presently being crushed and sold for use as railroad ballast; also minus 20-mm material and selected deposits of the crushed mill tailing sand are being used as coarse and fine aggregates for concrete. Although the predominant component of the rock is a granite that is chemically stable in most natural environments, other types of rock are present which must be investigated.

In assessing the suitability of aggregates for use in concrete, standard tests for coarse and fine aggregate are specified to determine the physical properties of the material. However, additional tests shoud be considered to detect potential reactivity between alkali in cement with certain mineral constituents of the aggregates.

2. OBJECTIVE OF THE PROJECT

The principal objective of this project is to determine if the concrete aggregates produced from the waste rock and mill tailings of Hilton mines contain minerals that are deleteriously reactive, with alkalis in cement, amounts sufficient to cause excessive expansion of concrete when it is frequently wetted, exposed to a hunid atmosphere, or in contact with moist ground. Stability in such environments is required of aggregate to be used in exposed concrete railroad ties.

3. BACKGROUND INFORMATION

3.1 Location - The crushed waste rock stockpile of over 75 millintons and over 15 million tons of crushed mill tailing sand accumulated at the Hilton mine in Quebec, abount 80 km East from Hull, Que. Production of iron ore concentrate ceased in 1975.

3.2 Preliminary petrographic examination - Work done by J. A. Soles (1) on random samples of the waste rock indicated that granite was predominant (40 - 80%), altered andesite and trap-rock were abundant (13 - 34%) and biotite-amphibole and talc-serpentine-mica schists were present (2 - 10%). The last type of schist may be chemically unstable. This favourable petrographic composition warranted further studies, using the crushed rock as coarse aggregate in concrete trial mixes.

3.3 Concrete trial mixes - In 1977 two samples of crushed rock were obtained and 2 concrete mixes, with a W/C ratio of 0.50 and 5% of entrained air were made by G. G. Carette and tested for strength and durability. The results indicated that concrete made with the waste rock coarse aggregate was of satisfactory strength (avg. 400 kg/cm^2 at 90 days) and showed good durability after 800 Fr/Th cycles (2).

3.4 Durability studies of CONTIE ties - A series of 33 railroad ties were manufactured one-at-a-time during July and August, 1981, using the crushed waste rock as coarse and mill tailings as fine aggregate.

Contie No.25, cast on August 24, was selected for durabi-

lity studies. As N. G. Zoldners (3) reported the concrete mixture had a 35 mm slump, 4.5% entrained air and a water/cement ratio W/C = 0.35.

Besides the 2.6 m Contie, also 4 standard 150 x 300-mm test cylinders and 4 prism specimens 88 x 100 x 400-mm were cast. Cylinders were used for compressive strength determination, whereas the prisms were exposed to freezing and thawing cycling. Two pieces 560 mm long were also cut for freeze-thaw testing from the middle section of the tie.

Freezing and thawing tests on the two concrete prisms and one piece of the tie were carried out at the CANMET laboratory in accordance with ASTM design. C 666, Procedure "B" (Rapid freezing in air and thawing in water).

After exposure to about 2000 cycles of freezing and thawing, both test prisms and the tie piece were tested by non-destructive and destructive methods. The results indicated that the durability of concrete in Contie Nr.25 was high. (3).

4. WORK PROCEDURES

4.1 FIELD WORK

4.1.1 Survey of stockpiles - After visual survey of the crushed rock stockpiles and the mill-tailing deposits, locations of 10 rock and 10 sand test holes were selected and marked by a numbered stick.

4.1.2 Sampling - Ten 800-kg samples of rock and ten 400-kg of mill-tailing sand were obtained and stored in separate steel drums.

A backhoe digger extracted the samples from a 4 to 6-ft depth in each testhole. The drums of rock samples and sand, properly identified by testhole No. , were taken to the plant for further processing.

4.1.3 Sample preparation - Each 800-kg rock sample was crushed separately to minus 19-mm ($\frac{3}{4}$-in.) size, dried on a concrete floor by hot-air blowers for several hours, then screened over a No.4 mesh sieve. The fines were discarded. A representative 200-kg sample of the coarse material was obtained, remixed, and then quartered into 4 sections. Two opposite sections of the quartered pile (R-A and R-B), about 50 kg each, were taken as samples for laboratory testing. The remaining 100 kg of rock were stored in covered and marked drums at the plant.

Representative 60-kg samples were obtained from each of the ten 400-kg sand samples after remixing on the floor. After drying for several hours by hot-air blowers, each sand lot was remixed, flattened and then quartered by showelling. The two opposite sections (S-A and S-B), about 15 kg each, were secured as test samples for laboratory testing. The remainder, about 30 kg of each sand sample was stored in marked drums at the plant.

The 10 pairs of 50-kg rock samples and 10 pairs of 15- kg sand samples, were filled into 40 closed 5-gallon metal cans,each identified by the test hole number. The entire lot, about 1300 kg of material, was shipped to Montreal on January 27, 1985, for testing at two experienced laboratories.

4.2 LABORATORY WORK

4.2.1 Laboratory work has been done in Montreal by the following two organizations:

A. Laboratoire de Béton Ltée did physical examination of aggregates by carrying out the following tests:

a) Soundness of aggregate by use of magnesium sulphate, 5 cycles - CSA, CAN3 - A23.2 - 9A;

b) Specific gravity and absorption - ASTM C127 and C128;

c) Sieve analysis of sand - CSA, CAN3 - A23.2 - 2A;

d) Concrete prism tests - CSA, CAN3 - A23.2 - 14A.

B. Ecole Polytechnique did the following work:

a) Petrographic examination - ASTM C295, CSA, A23.2 -15A, by Jean Berard, Ph.D., Geologist;

b) Chemical tests - ASTM C 289, by the Laboratoire de Géochimie Analytique, Victor J.Kubat;

c) Mortar bar tests - ASTM C 227, by Prof. Jules Houde.

In order to obtain preliminary information about the mineralogical composition of the rock, a general petrographic examination of the material is essential. It will indicate whether the material contains minerals that are deleteriously reactive with alkalies in cement. Favourable results warrant further studies in assesing this material for use as aggregate in concrete exposed to moist environmental conditions.

4.2.2 Petrographic examination - All rock and sand samples were examined petrographically by Dr. Jéan Bérard, geologist at the Ecole Polytechnique, University of Montreal. His report of Febr. 28, 1985 is enclosed as Appendix A.

The report indicates that all samples contain the same

mineral constituents and the relative percentages vary little. The sand composition is given on a volume basis and the crushed rock composition on a weight basis.

Because of greater surface area per unit weight, the sand is more exposed to potential chemical reactions than the coarse aggregate. Therefore a more detailed petrographic analysis was done on sand than on rock particles. About 150 particles were counted for each sand-size fraction to obtain volume percentage of particle types; weight percentages were not calculated.

Exept for pyrite (and little pyrrhotite) all minerals are chemically stable in both, atmospheric and portland cement concrete environments. Magnetite could oxydize if exposed to a very acidic environment.

The mechanical properties are excellent for the granite or tor the minerals derived from it and the only mechanically undesirable minerals are biotite and chlorite. The serpentine is rich in magnetite and strongly magnetic; all the free magnetite present in the fine fractions was probably derived from serpentinite.

The biotite-actinolite-chlorite gneiss is slightly friable but the constituents are fresh and the only disadvantage would be the fact that more mica and chlorite would be freed by attrition.

Minor isolated constituents such as zircon, calcite, hornblende, etc.... have been ignored in these analyses.

The general petrographic compositions of the ten rock samples are shown in Table 1, grouped for each sample in 3 iden-

tical mineral groups, varying in weight percentages as follows:

Granite-granite gneiss - 47% to 62%

Biotite actinolite gneiss - 15% to 36%

Serpentinite - 13% to 33%

The petrographic number (PN) for each of the ten rock and ten sand samples was determined according to the CSA standard test method A 23.2 - 15A (Appendix B, Table B2). The PN for the 10 rock samples ranged from 132 to 172. To evaluate the chemical stability of aggregate material containing some of the potentially alkali reactive minerals (biotite-actinolite-gneiss), three rock samples with widely ranging PN values were selected for use in the aggregate-cement alkali reaction studies.

The rock samples selected are as follows:

Rock Samples	Petrographic Number
R - 1A	132
R - 4A	160
R - 8A	172

Mineral compositions of the ten sand samples were determined by grouping the mineral particles of each size and calculating the PN value for these size fraction as well as for the whole sand sample. The PN value for the 10 sand samples ranged from 123 to 150. The results of petrographic analyses and the PN values of each sand sample are summarized in Table 2.

For use in concrete mixes it is desirable that the grading of fine aggregate is within the specified standard grading limits.

Table 1 - Petrographic analyses of 10 samples of rock.

Rock sample	Prinzipal constituents of the rock sample						Petrographic Number by CSA Standard CAN3 A23.2-15A
	Granite-granite gneiss %	Factor F	Biotite actinolite gneiss %	Factor F	Serpentinite %	Factor F	
R-1A	51	1	16	3	33	1	132
R-2A	62	1	15	3	23	1	130
R-3A	56	1	31	3	13	1	162
R-4A	47	1	30	3	23	1	160
R-5A	60	1	26	3	14	1	152
R-6A	54	1	25	3	21	1	150
R-7A	60	1	25	3	15	1	150
R-8A	49	1	36	3	15	1	172
R-9A	50	1	22	3	28	1	144
R-10A	55	1	28	3	17	1	156

As per CSA stand.test method CAN3-A23.2-15A - Rock composition in % on a weight basis.
- Classification of rock types by factor F: good-1; fair-3; poor-6; deleterious-10.

Table 2 - Petrographic analyses of 10 samples of sand. (page 1)

COMPOSITION	Sample S-1A		Sample S-2A		Sample S-3A		Sample S-4A		Sample S-5A		Sample S-6A		Sample S-7A		Sample S-8A		Sample S-9A		Sample S-10A	
	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F
Size: 2.50 mm	0.0		31.8		0.0		0.0		1.3 g		4.8 g		4.0 g		21.8		0.0		13.8 g	
Quartz			9	1					16	1	7	1	21	1	41	1			48	1
Feldspar			51	1					38	1	24	1	32	1	48	3				
Biotite			4	6					10	6	11	6	47	3					31	3
Chlorite			4	6					10	6	3	6								
Actinolite			9	1					10	1										
Serpentinite			21	1					10	1	50	1			9	1			19	1
Pyrite - pyrrhotite			2	1					6	1	5	1			2	1			2	1
Petrogr.number:			140						200		146		194		196				162	
Size: 1.25 mm	46.4		127.6		51.8		24.0		18.9		45.7		44.8		166.8		74.5		144.6 g	
Quartz	7	1	12	1	4	1	13	1	16	1	12	1	5	1	3	1	6	1	5	1
Feldspar	44	1	48	1	48	1	47	1	38	1	38	1	40	1	43	1	36	1	40	1
Biotite	4	6	2	6	2	6	2	6	10	6	2	6	3	6	3	6	3	6	4	6
Chlorite	6	6	5	6	2	6	2	6	10	6	8	6	2	6	2	6	3	6	3	6
Actinolite & hornblen.	15	1	4	1	14	1	13	1	10	1	13	1	14	1	22	1	16	1	22	1
Serpentinite	22	1	22	1	30	1	11	1	10	1	22	1	28	1	24	1	28	1	25	1
Pyrite & pyrrhotite	1	1	2	1			8	1	6	1	5	1	4	1	1	1	1	1	1	1
Magnetite	1	1	5	1			4	1					4	1	2	1	7	1		
Petrogr.number:	150		135		120		120		200		150		125		125		130		135	
Size: 630 µm	147 g		202.2		179.1		117.8		93.1		61 g		203.5		348 g		221.7		313.9 g	
Quartz	6	1	14	1	13	1	13	1	16	1	12	1	9	1	10	1	13	1	15	1
Feldspar	41	1	42	1	51	1	57	1	41	1	35	1	36	1	44	1	41	1	58	1
Biotite	2	6	2	6	2	6	2	6	4	6	7	6	2	6	3	6	6	6	3	6
Chlorite	7	6	2	6	2	6	2	6	6	6	5	6	2	6	2	6	6	6	2	6
Actinolite & hornblen.	31	1	22	1	17	1	16	1	21	1	23	1	24	1	23	1	20	1	12	1
Serpentinite	4	1	8	1	11	1	6	1			16	1	18	1	15	1	4	1	23	1
Pyrite & pyrrhotite	3	1	6	1	2	1	1	1	7	1	1	1	4	1	2	1	3	1	2	1
Magnetite	6	1	4	1	2	1	3	1	5	1			5	1	1	1	7	1	3	1
Petrogr.number:	145		120		120		120		150		160		120		125		160		125	

Table 2 - Petrographic analyses of 10 samples of sand.

(continued)

COMPOSITION	Sample S-1A		Sample S-2A		Sample S-3A		Sample S-4A		Sample S-5A		Sample S-6A		Sample S-7A		Sample S-8A		Sample S-9A		Sample S-10A	
	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F
Size: 315 µm g:	211.2		176.8		240.6		217.9		218 g		210 g		250.9		158.8		180.8		182 g	
Quartz	10	1	17	1	13	1	15	1	20	1	15	1	11	1	13	1	15	1	12	1
Feldspar	37	1	44	1	46	1	43	1	33	1	36	1	34	1	50	1	35	1	43	1
Biotite	1	6	3	6	4	6	3	6	1	6	5	6	4	6	3	6	5	6	4	6
Chlorite	2	6	2	6	4	6	3	6	1	6	3	6	2	6	2	6	5	6	4	6
Actinolite & serpent.	39	1	20	1	15	1	28	1	31	1	33	1	36	1	16	1	26	1	24	1
Pyrite & pyrrhotite	7	1	7	1	7	1			7	1	3	1	7	1	4	1	6	1	2	1
Magnetite	4	1	5	1	3	1	5	1	7	1	5	1	2	1	3	1	8	1	4	1
Serpentinite			2	1	8	1							4	1	9	1			7	1
Petrogr.number:	115		125		140		130		110		140		130		125		150		140	
Size: 160 µm g:	152 g		101.1		154.4		17o.2		215.6		158.8		164 g		50.4		104.6		72 g	
Quartz	11	1	23	1	15	1	23	1	21	1	16	1	15	1	8	1	14	1	10	1
Feldspar	32	1	29	1	45	1	31	1	14	1	30	1	29	1	36	1	33	1	35	1
Biotite	4	6	4	6	3	6	5	6	1	6	2	6	5	6	7	6	7	6	6	6
Chlorite	4	6	3	6	1	6	2	6	1	6	1	6	1	6	3	6	2	6	1	6
Actinolite & serpent.	34	1	29	1	26	1	33	1	49	1	33	1	28	1	34	1	29	1	33	1
Pyrite & pyrrhotite	11	1	6	1	9	1	3	1	7	1	12	1	15	1	9	1	9	1	6	1
Magnetite	4	1	6	1	2	1	3	1	7	1	6	1	3	1	3	1	6	1	6	1
Serpentinite													4	1					3	1
Petrogr.number:	140		135		120		135		110		115		130		150		145		135	
Size: 80 µm g:	73.9		53.5		72.5		94.4		95 g		61.8		75.1		30.3		70.9		41.1	
Quartz	11	1	12	1	16	1	17	1	31	1	10	1	14	1	8	1	14	1	10	1
Feldspar	31	1	43	1	44	1	49	1	18	1	32	1	30	1	38	1	32	1	36	1
Biotite	4	6	1	6	3	6	1	6	2	6	1	6	5	6	5	6	2	6	5	6
Chlorite	4	6	1	6	1	6	1	6	5	6	1	6	1	6	3	6	7	6	1	6
Actinolite & serpent.	33	1	29	1	24	1	20	1	36	1	29	1	27	1	34	1	28	1	32	1
Pyrite & pyrrhotite	13	1	9	1	10	1	9	1	5	1	14	1	14	1	9	1	12	1	7	1
Magnetite	4	1	5	1	2	1	3	1	3	1	13	1	3	1	3	1	5	1	6	1
Serpentinite													6	1					3	1
Petrogr.number:	140		110		120		110		135		110		130		140		145		130	
Sample petrogr.number:	133		126		127		126		123		136		127		129		150		132	

4.2.3 Physical tests - These tests include:

(A) Sieve analyses - in accordance with CSA Test Method CAN3 A23.2-2A - Sieve analysis of fine and coarse aggregate.

(B) Amount of fines - CSA Test Method A23.2-5A - Amount of material finer than 80 μm (minus 200 Mesh) in aggregate.

(C) Soundness of aggregate - CSA Test Method A23.2-9A - Soundness of aggregate by use of magnesium sulphate, 5 cycles.

(D) Specific gravity and absorption - ASTM Standard Test Method C 127 (coarse aggregate) and C 128 (fine aggregate).

A. Sieve analyses of sand - all 10 sand test samples Nos.S-1A to S-10A, as well as the reference sand from Joliette,Que., were tested for particle size grading according to the CSA. Sieve analyses shown in Table 3 indicate that most of the mill tailing sand samples are too fine for use in concrete mixes. As the best sand samples the following 3 were selected and accepted as fine aggregate for concrete test mixes:

Sand sample No.	Fineness modulus	Petrographic number
S - 2A	2.31	126
S - 8A	2.67	129
S - 10A	2.46	132

Particle size gradings of the 3 sand samples are shown in Figure 1.

B. Amount of fines - The material finer than 80 μm in the 10 samples of sand amounted from 5.5 to 9.5%, which is more than maximum acceptable limit of 5.0%. In the sand sample from Joliette the minus 80 μm material was only 0.6%.

Table 3

SIEVE ANALYSIS OF FINE AGGREGATE

CSA TEST METHOD CAN3 A23.2-2A

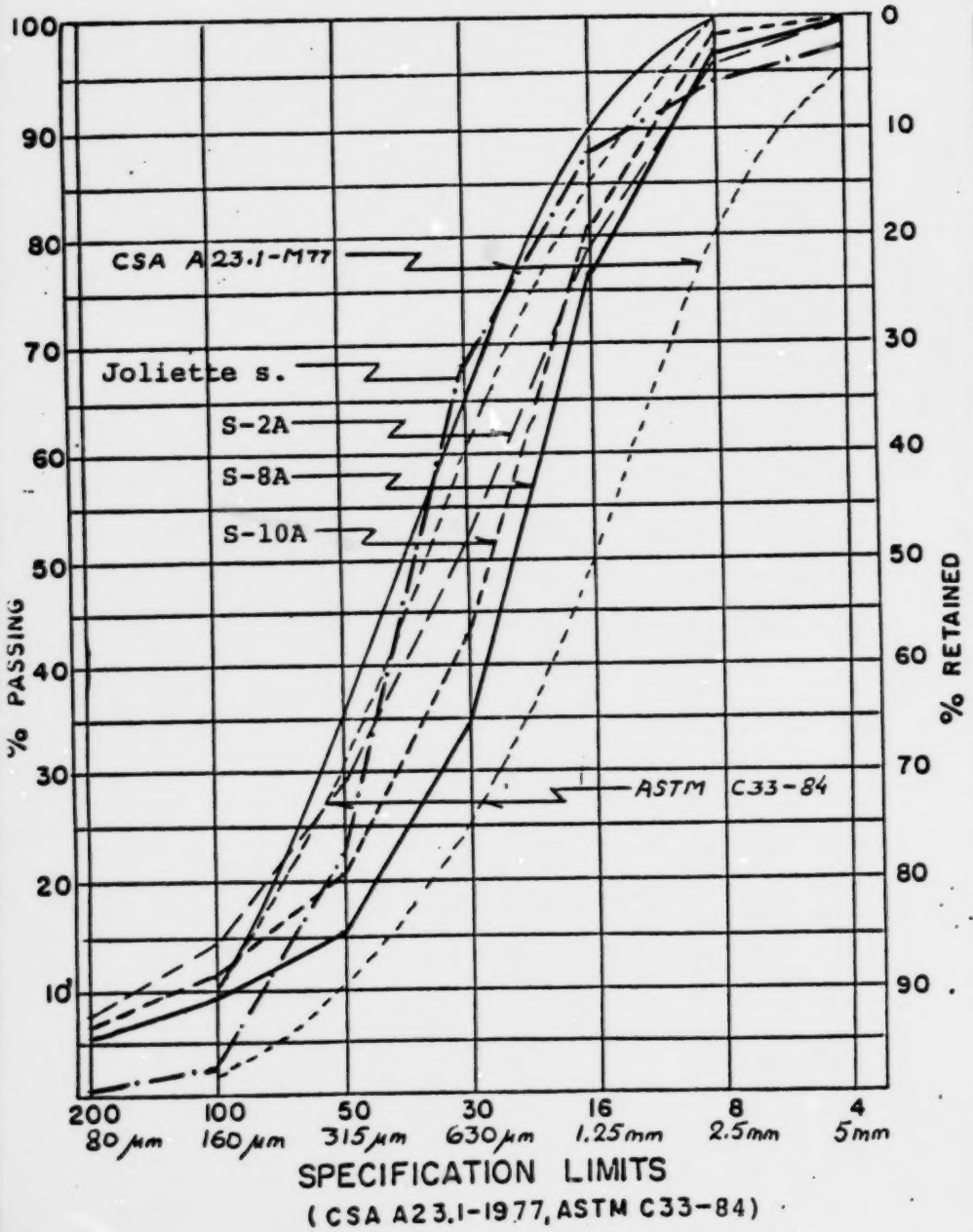
AMOUNT OF MATERIAL FINER THAN 80 µm IN AGGREGATE

CSA TEST METHOD CAN3 A23.2-5A

SAMPLE NO	10 mm	5 mm	2,5 mm	1,25 mm	630 µm	315 µm	160 µm	80 µm	FINENESS MODULUS
S-1A	-	100	99,3	92,6	71,3	40,7	18,7	8,0	1,77
S-2A	100	99,6	95,7	78,7	51,8	28,3	14,8	7,7	2,31 ✓
S-3A	-	100	99,3	92,5	69,1	37,7	17,5	8,0	1,84
S-4A	-	100	99,6	96,1	78,9	48,1	23,3	9,5	1,54
S-5A	-	100	99,8	97,1	83,7	52,4	21,4	7,7	1,46
S-6A	-	100	99,3	92,6	68,9	38,0	14,6	5,5	1,87
S-7A	100	99,9	99,5	93,9	68,4	36,9	16,3	6,9	1,85
S-8A	100	99,9	97,3	77,0	34,5	15,2	9,1	5,4	2,67 ✓
S-9A	100	99,8	99,0	88,6	57,5	32,1	17,4	7,4	2,06
S-10A	100	99,9	98,4	80,9	42,8	20,6	11,9	6,9	2,46 ✓
Sand from Joliette	100	97,3	94,5	87,6	67,8	22,4	2,8	0,6	2,28
Grading limits	100	100 95,0	100 80,0	90,0 50,0	65,0 25,0	35,0 10,0	10,0 2,0	3,0* 0	3,10 2,30

* : This limit may be increased to a maximum of 5,0 percent, provided that the clay size material (finer than 2 µm) does not exceed 1 percent of the total fine aggregate sample.

— : Percentage passing out of the grading limits fineness modulus out of limits.



% PASSING				
SIEVE SIZES	S-2A	S-8A	S-10A	Joliette sand
4 MESH 5mm	99.6	99.9	99.9	97.3
8 2.5mm	95.7	97.3	98.4	94.5
16 1.25mm	78.7	77.0	80.9	87.6
30 630 m	51.8	34.5	42.8	67.8
50 315 m	28.3	15.2	20.6	22.4
100 160 m	14.8	9.1	11.9	2.8
200 80 m	7.7	5.4	6.9	0.6
F.M.	2.31	2.67	2.46	2.28
% VOIDS				
Graphs:	- - -	———	- - -	- · - · -

SIEVE ANALYSIS AND SAND GRADING CHART

Fig.1

C. Soundness of aggregate - The soundness tests were carried out on coarse and fine aggregate separately:

Coarse aggregate.

The results of tests made on samples R-1A, R-4A and R-8A are shown in Table 4. Of the 3 rock samples as coarse aggregate for concrete mixes was selected sample R-4A. Some of it was crushed to sand sizes as specified by ASTM C 227 and was used in preparation of mortar test bars No.4463-04 and -05.

Fine aggregate.

The results of tests made on samples S-2A, S-8A and S-10A are shown in Table 5. These results indicate that all 3 samples of sand meet the soundness requirements of maximum loss of 16%. For the best grading the sand sample S-8A was selected for use in concrete mixes.

D. Specific gravity and absorpion tests - The results of these tests made on coarse aggregate samples R-1A, R-4A and R-8A, as well as the results of tests on fine aggregate samples S-2A, S-8A and S-10A are shown in Table 6.

Also shown are results of the same tests made on the reference sand from Joliette.

SOUNDNESS OF AGGREGATE BY USE OF MAGNESIUM SULPHATE, 5 CYCLES

CSA TEST METHOD CAN3 A23.2-9A

Table 4

COARSE AGGREGATE

SIEVE SIZE PASSING	SIEVE SIZE RETAINED	GRADING OF ORIGINAL SAMPLE PERCENT	ACTUAL PERCENTAGE LOSS	CORRECTED PERCENTAGE LOSS
Sample R-1A				
20 mm	10 mm	-	15,5	-
10 mm	5 mm	-	22,9	-
Sample R-1A (test made by another laboratory)				
20 mm	10 mm	-	15,2	-
10 mm	5 mm	-	21,0	-
Sample R-4A				
20 mm	10 mm	-	11,6	-
10 mm	5 mm	-	25,1	-
Sample R-8A				
20 mm	10 mm	-	10,8	-
10 mm	5 mm	-	11,6	-

The maximum loss allowable on coarse aggregate according to CSA Standard CAN3 A23.1-M77 is 12% for concrete classes of exposure A and B and 18% for concrete classes of exposure C and D.

NOTE : Tests were performed from March 18 to March 26, 1985.

SOUNDNESS OF AGGREGATE BY USE OF MAGNESIUM SULPHATE, 5 CYCLES

CSA TEST METHOD CAN 3 A23.2 -9A

FINE AGGREGATE

Table 5

SIEVE SIZE PASSING	SIEVE SIZE RETAINED	GRADING OF ORIGINAL SAMPLE PERCENT	ACTUAL PENCENTAGE LOSS	CORRECTED PERCENTAGE LOSS
Sample S-2A				
10 mm	5 mm	0,4	-	0,05
5 mm	2,5 mm	3,9	13,0	0,51
2,5 mm	1,25 mm	17,0	13,7	2,33
1,25 mm	630 µm	26,9	10,8	2,91
630 µm	315 µm	23,5	5,3	1,25
315 µm	160 µm	13,5	-	-
160 µm	-	14,8	-	-
TOTAL :		100,0		7,05
Sample S-8A				
10 mm	5 mm	0,1	-	0,02
5 mm	2,5 mm	2,6	21,2	0,55
2,5 mm	1,25 mm	20,3	14,8	3,00
1,25 mm	630 µm	42,5	9,2	3,91
630 µm	315 µm	19,3	6,2	1,20
315 µm	160 µm	6,1	-	-
160 µm	-	9,1	-	-
TOTAL :		100,0		8,68
Sample S-10A				
10 mm	5 mm	0,1	-	0,02
5 mm	2,5 mm	1,5	23,0	0,34
2,5 mm	1,25 mm	17,5	19,2	3,36
1,25 mm	630 µm	38,1	14,1	5,37
630 µm	315 µm	22,2	7,2	1,60
315 µm	160 µm	8,7	-	-
160 µm	-	11,9	-	-
TOTAL :		100,0		10,69

Table 6

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATES

STANDARD TEST METHOD ASTM C 127

SAMPLE NO	BULK SPECIFIC GRAVITY (SATURATED SURFACE DRY BASIS)	ABSORPTION %
R-1A	2,66	1,1
R-4A	2,67	1,2
R-8A	2,70	0,7

R = Rock

SPECIFIC GRAVITY AND ABSORTION OF FINE AGGREGATES

STANDARD TEST METHOD ASTM C 128

SAMPLE NO	BULK SPECIFIC GRAVITY (SATURATED SURFACE DRY BASIS)	ABSORPTION %
S-2A	2,62	0,9
S-8A	2,61	1,0
S-10A	2,57	0,7
Sand from Joliette (Francon)	2,68	0,8

S = Sand

NOTE : Tests were performed from April 17 to April 19, 1985.

Coarse aggregates were washed on screen No 4 before making those tests.

4.2.4 Chemical tests - The chemical tests were made at Ecole Polytechnique, Laboratoire de Geochemie Analytique, according to ASTM Test Method C - 289, Potential reactivity of aggregates (Chemical method). This method gives the potential reactivity of an aggregate with alkalies in portland cement concrete, as indicated by the amount of reaction during 24 h at 80° C between 1 N sodium hydroxide solution and aggregate that has been crushed and sieved to pass a 300 μm (No.50) sieve and be retained on a 150 μm (No.100) sieve.

A potentially deleterious degree of alkali reactivity is indicated if any of the Rc (reduction of alkalinity) and Sc (dissolved silica) points lie on the deleterious side of the solid curve. Tests were performed on ten rock and ten sand samples.

The results of the 10 rock samples are compiled in Table 7. The Rc values for these 10 rock samples varies from 28 to 77 and Sc values from 8.8 to 15.5. The resultant 10 points are shown on the graph in Figure 2. They are all located within the area of innocuous concrete aggregates.

The chemical test was also made on the HCl - insoluble part (90.5%) of rock sample R - 10A. The resultant point at Rc = 50 and Sc = 45.7, is also located within the area of innocuous aggregates, as shown in Figure 3.

Table 7

ECOLE POLYTECHNIQUE - GEOCHIMIE ANALYTIQUE
Campus de l'Université de Montréal
Case Postale 6079, Succursale "A"
Montréal (Québec) H3C 3A7

Analyse #	Echantillon #		
85-0630	# R-1-A	Rc = 64 Sc = 10.3	Inoffensif
85-0631	# R-2-A	Rc = 74 Sc = 9.5	Inoffensif
85-0632	# R-3-A	Rc = 54 Sc = 15.5	Inoffensif
85-0633	# R-4-A	Rc = 77 Sc = 11.8	Inoffensif
85-0634	# R-5-A	Rc = 64 Sc = 12.6	Inoffensif
85-0635	# R-6-A	Rc = 63 Sc = 8.8	Inoffensif
85-0636	# R-7-A	Rc = 46 Sc = 10.7	Inoffensif
85-0637	# R-8-A	Rc = 28 Sc = 12.8	Inoffensif
85-0638	# R-9-A	Rc = 59 Sc = 10.5	Inoffensif
85-0639	# R-10-A	Rc = 34 Sc = 13.4	Inoffensif

Chemical tests on
10 rock samples

(ASTM Method C 289)

Guy Perrault, ing., Ph.D.
Laboratoire de Géochimie Analytique

Victor J. Kubat
Responsable,
Laboratoire de Géochimie Analytique

Fig.2

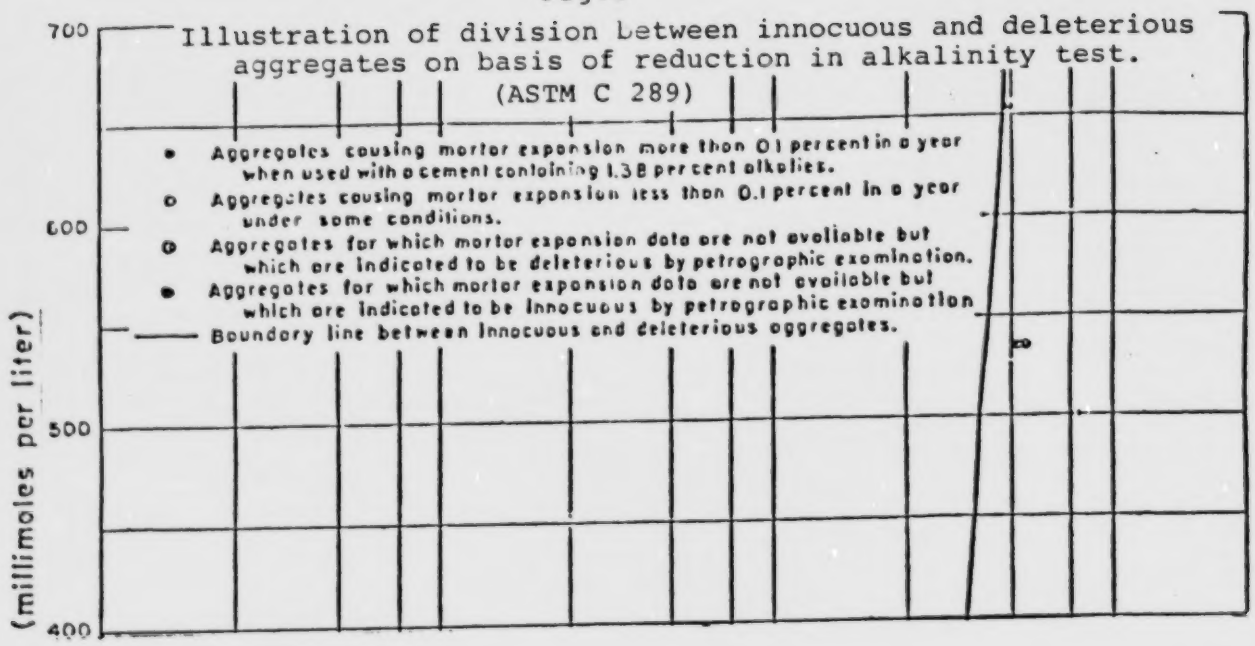


Illustration of division between innocuous and deleterious aggregates on basis of reduction in alkalinity test.
(ASTM C 289)
Aggregates causing mortar expansion more than 0.1 percent in a year when used with a cement containing 1.38 per cent alkalies.
Aggregates causing mortar expansion less than 0.1 percent in a year under some conditions.
Aggregates for which mortar expansion data are not available but which are indicated to be deleterious by petrographic examination.
Aggregates for which mortar expansion data are not available but which are indicated to be innocuous by petrographic examination
Boundary line between innocuous and deleterious aggregates.
(millimoles per liter)
700
600
500
400

Rock samples

1) R-1-A:	Rc = 64.0;	Sc = 10.3;	6) R-6-A:	Rc = 63.0;	Sc = 8.8;
2) R-2-A:	Rc = 74.0;	Sc = 9.5;	7) R-7-A:	Rc = 46.0;	Sc = 10.7;
3) R-3-A:	Rc = 54.0;	Sc = 15.5;	8) R-8-A:	Rc = 28.0;	Sc = 12.8;
4) R-4-A:	Rc = 77.0;	Sc = 11.8;	9) R-9-A:	Rc = 59.0;	Sc = 10.5;
5) R-5-A:	Rc = 64.0;	Sc = 12.6;	10) R-10-A:	Rc = 34.0;	Sc = 13.4.

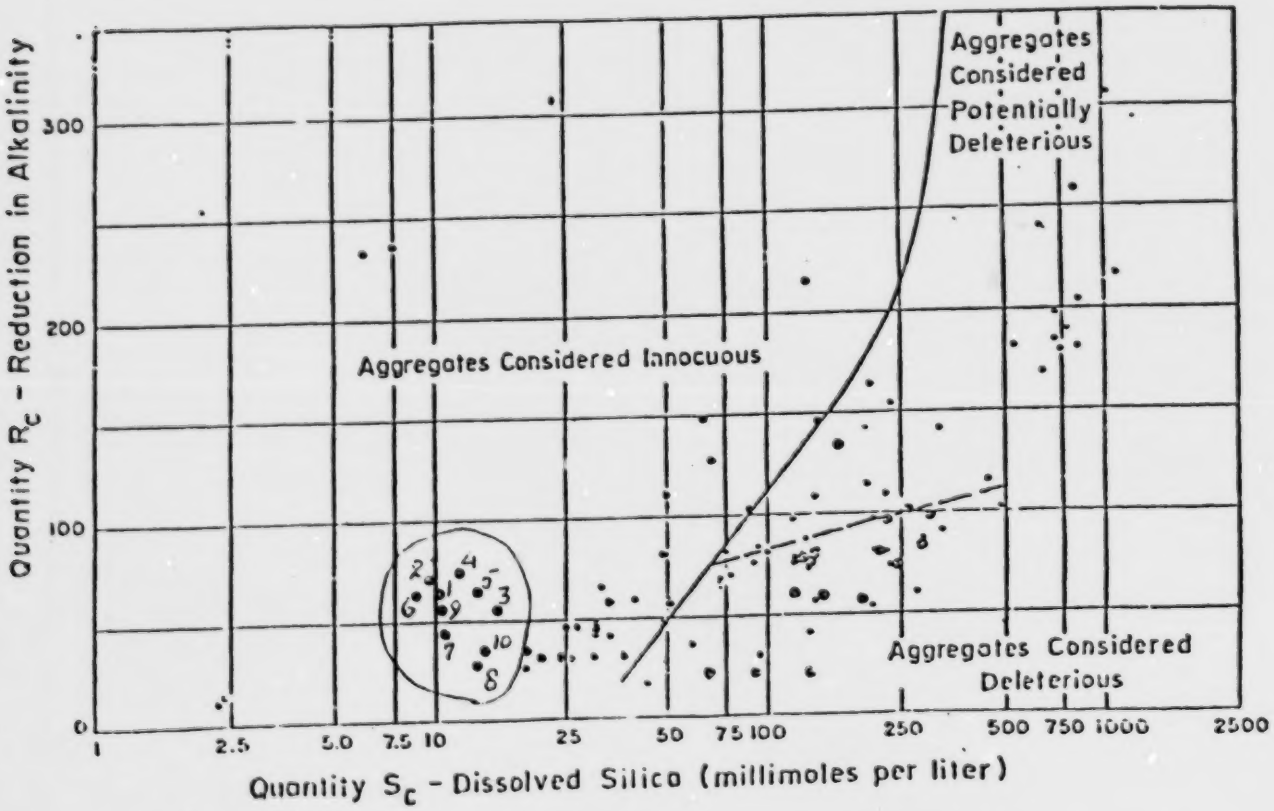
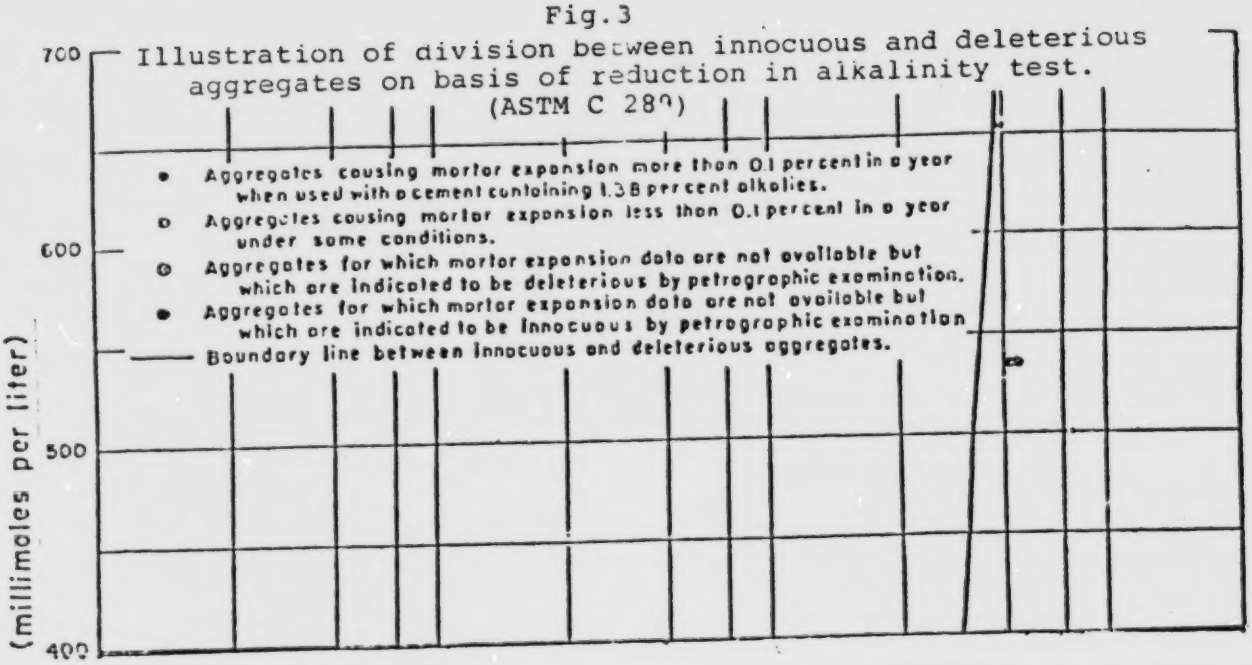


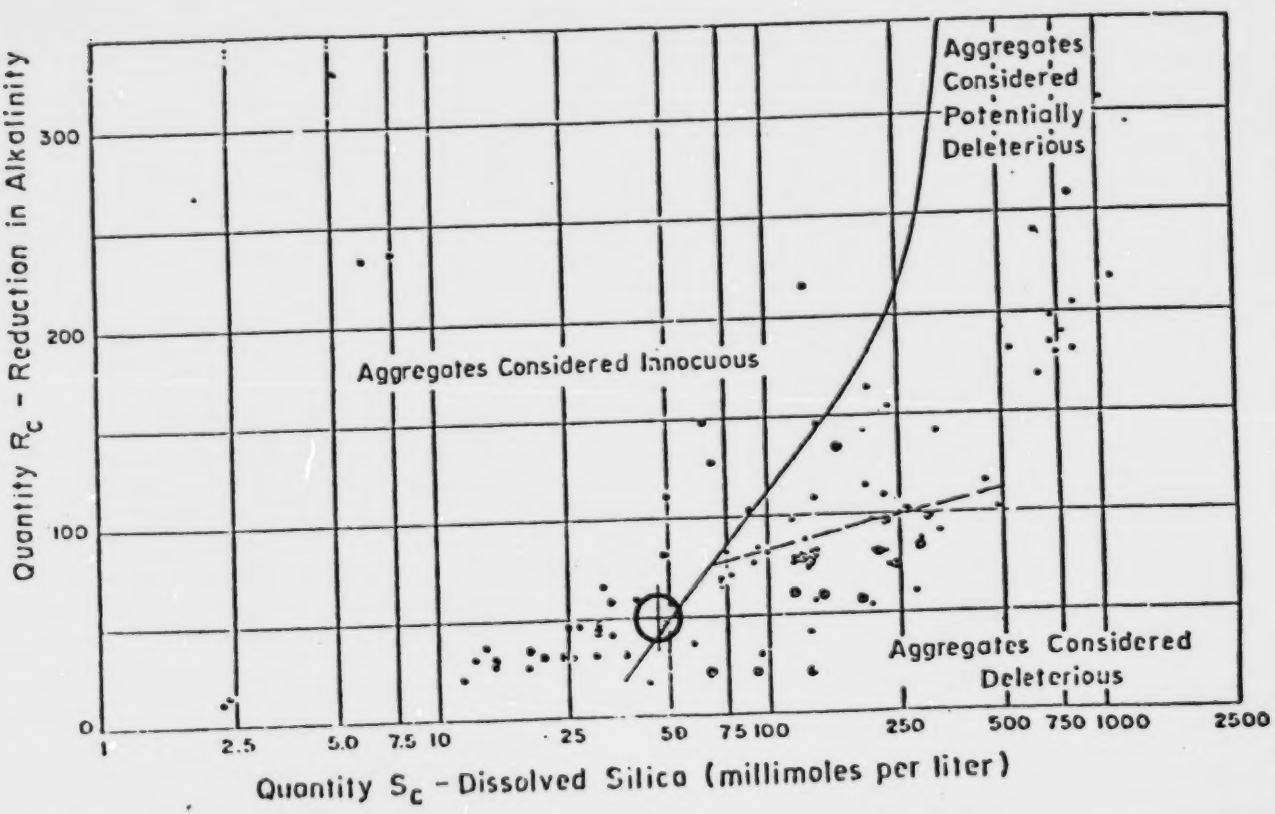
Fig.3

Illustration of division between innocuous and deleterious aggregates on basis of reduction in alkalinity test. (ASTM C 289)


700
600
500
400
(millimoles per liter)
• Aggregates causing mortar expansion more than 0.1 percent in a year when used with a cement containing 1.38 percent alkalies.
o Aggregates causing mortar expansion less than 0.1 percent in a year under some conditions.
⊙ Aggregates for which mortar expansion data are not available but which are indicated to be deleterious by petrographic examination.
• Aggregates for which mortar expansion data are not available but which are indicated to be innocuous by petrographic examination
Boundary line between innocuous and deleterious aggregates.

Echantillon R-10-A insoluble Rc = 50 Sc = 45.7 Inoffensif

% insoluble = 90.5 %



The results of the 10 sand samples are compiled in Table 9. The Rc values vary from 30 to 78 and Sc values from 7.0 to 10.8. The resultant 10 points are marked on the graph in Figure 4. These points for sand samples are also all located within the area which represents innocuous concrete aggregates.

Although the petrographic examinations and chemical analyses both indicated that these aggregates could be considered as innocuous, additional mortar bar and concrete prism expansion tests were made, using high — and low — alkali portland cements.

The high - alkali cement used was Type 10 from the Canada Cement Lafarge, Bath, Ontario, plant; the low - alkali cement was from the St. Constant, Québec, plant. The alkali content of each cement is determined in the Table 8, below:

Table 8

Determination of alkali content in cement

Cement Type: Manufacturer: Plant:	Type 10 CANADA CEMENT LAFARGE Bath, Ontario	Type 10 CANADA CEMENT LAFARGE St.Constant, Québec.
Na_2O	0.30%	0.15%
K_2O	1.06%	0.49
Equivalent Alkalis $0.658\ K_2O + Na_2O$	1.00%	0.47%

Table 9

ECOLE POLYTECHNIQUE - GEOCHIMIE ANALYTIQUE
Campus de l'Université de Montréal
Case Postale 6079, Succursale "A"
Montréal (Québec) H3C 3A7

Analyse #	Echantillon #		
85-0640	# S-1-A	Rc = 38 Sc = 7.3	Inoffensif
85-0641	# S-2-A	Rc = 78 Sc = 9.3	Inoffensif
85-0642	# S-3-A	Rc = 48 Sc = 9.0	Inoffensif
85-0643	# S-4-A	Rc = 45 Sc = 9.3	Inoffensif
85-0644	# S-5-A	Rc = 33 Sc = 7.1	Inoffensif
85-0645	# S-6-A	Rc = 55 Sc = 7.0	Inoffensif
85-0646	# S-7-A	Rc = 30 Sc = 7.7	Inoffensif
85-0647	# S-8-A	Rc = 33 Sc = 9.5	Inoffensif
85-0648	# S-9-A	Rc = 38 Sc = 7.5	Inoffensif
85-0649	# S-10-A	Rc = 42 Sc = 10.8	Inoffensif

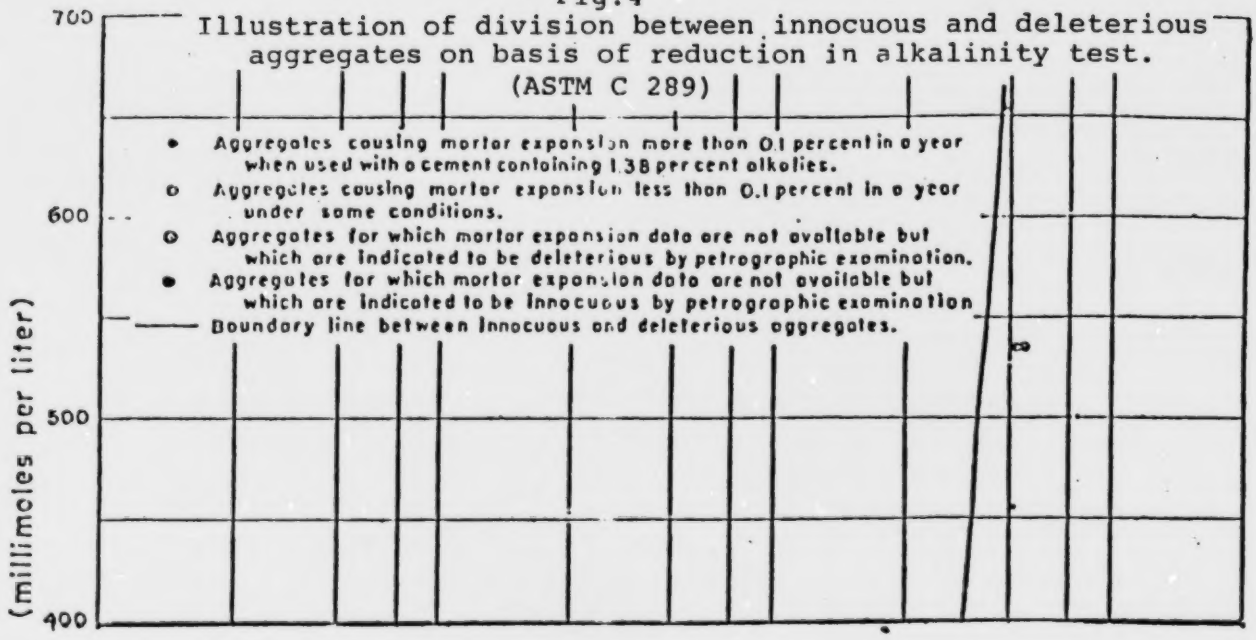
Chemical tests on
10 sand samples
(ASTM Method C 289)

Guy Perrault, ing., Ph.D.
Laboratoire de Géochimie Analytique

Victor J. Kubat
Responsable,
Laboratoire de Géochimie Analytique

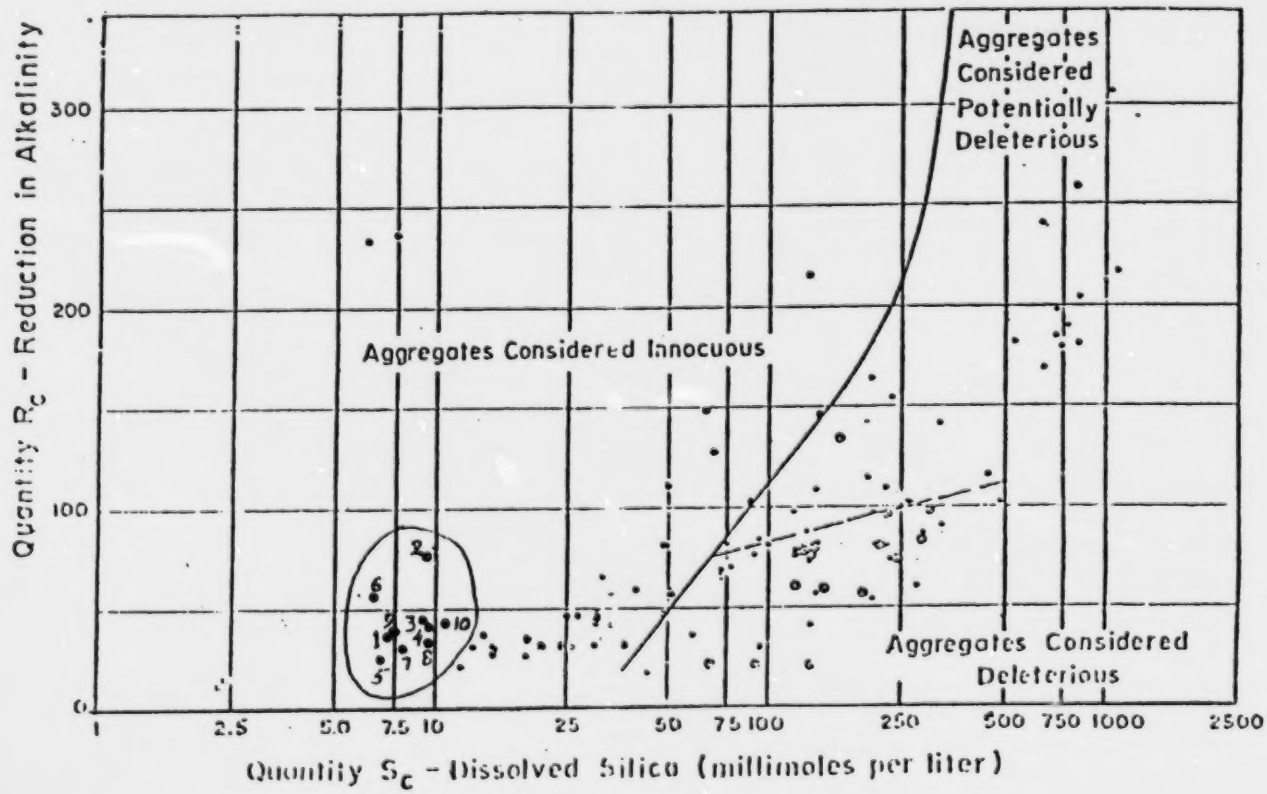
Fig.4

Illustration of division between innocuous and deleterious aggregates on basis of reduction in alkalinity test. (ASTM C 289)


700
600
500
400
(millimoles per liter)
• Aggregates causing mortar expansion more than 0.1 percent in a year when used with a cement containing 1.38 per cent alkalies.
o Aggregates causing mortar expansion less than 0.1 percent in a year under some conditions.
⊙ Aggregates for which mortar expansion data are not available but which are indicated to be deleterious by petrographic examination.
● Aggregates for which mortar expansion data are not available but which are indicated to be innocuous by petrographic examination
Boundary line between innocuous and deleterious aggregates.

Sand samples

1) S-1-A:	Rc = 38.0;	Sc = 7.3;	6) S-6-A:	Rc = 55.0;	Sc = 7.0;
2) S-2-A:	Rc = 78.0;	Sc = 9.3;	7) S-7-A:	Rc = 30.0;	Sc = 7.7;
3) S-3-A:	Rc = 48.0;	Sc = 9.0;	8) S-8-A:	Rc = 33.0;	Sc = 9.5;
4) S-4-A:	Rc = 45.0;	Sc = 9.3;	9) S-9-A:	Rc = 38.0;	Sc = 7.5;
5) S-5-A:	Rc = 33.0;	Sc = 7.1;	10) S-10-A:	Rc = 42.0;	Sc = 10.8.



4.2.5 Mortar bar tests - The mortar bar tests were made at Ecole Polytechnique, Montreal, accordind to ASTM Standard Method C 227, Potential alkali reactivity of cement - aggregate combination (Mortar - bar method).

Sufficient amount of coarse aggregate from sample R - 8A was sent by the Laboratoire de Béton to the lab at Ecole Polytechnique for crushing to produce fine aggregate of a grading specified by the test method.

Two mortars were prepared: Mix No.4463 -04 with a high - - alkali cement from Bath plant (1.0% equiv. alkalis) and Mix No.4463 - 05 with a low - alkali cement from St.Constant plant (0.47% equiv. alkalis). Test specimens used for measuring the length change of hardened mortars were 1 x 1 x 11¼-in. (25 x 25 x 285-mm) bars, having a 10-in. (250-mm) effective gauge length. A set of four test specimens were made in two batches from each of the two mortars. The two mortar bars made from the first batch of each set were marked A_1 and A_2 , whereas those from the second batch were B_1 and B_2 . The two batches of each set were identical and composed as follows:

Cement	- 300 g
Sand	- 675 g
Water	- 130 g

The mortar bars were prepared as specified in ASTM C 227, placed in moist curing room for 24 h and then removed from the moulds. While being protected from loss of moisture the test bars were measured for initial length to the nearest 0.0001 in. (0.002 mm).

Both sets of test specimens - a total of 8 mortar bars - were placed on end over water in the closed storage container.

After sealing the container was stored at a temperature of 100 ± 3°F (37.8 ± 1.7°C) for 12 days. After removal of container and storage at 73.4 ± 3°F (23 ± 1.7°C) for at least 16 h before opening the container, measurements of test bars were made at 14-day age. Additional measurements were made at ages of 1,2,3, 4,6,9 and 12 months.

Specimens were always placed in the comparator with the same end uppermost; after measurement, they were replaced in inverted position compared with the previous period.

The difference between the initial length of the specimen and the length at each period of measurement was calculated to the nearest 0.001% of the effective gauge length. The length changes of the test specimens are shown in Table 10. The average of the readings of the four specimens of each set was calculated and graphs for test set No. 4463 - 04 (with high-alkali cement) and No. 4463 - 05 (with low-alkali cement) are drawn in Figure 5. Graph "04" shows length changes of mortar bars made with high-alkali and graph "05" of bars with low-alkali cement. These graphs indicate that 4-month and 1-year readings are, for some unknown reason, inconsistent with the general trend of both graphs and have to be ignored. Readings taken at some later date may establish the correct continuation for these graphs.

Table 10

Length changes of mortar bars.

ASTM C 227-71

BARREAU NO. | ÂGE DE L'ÉCHANTILLON

		INITIALE	14 JOURS	1 MOIS	2 MOIS	3 MOIS	4 MOIS	6 MOIS	9 MOIS	12 MOIS	18 MOIS	24 MOIS
VARIATION TOTALE DE LONGUEUR DES BARREAUX de 1" à 1" à 10" EXPRIMÉE EN 0,0001"												
13-84	A_1	0	0	-0,0002		-0,0003	-0,0012	+0.0006	+0.0005	+0.0001		
	A_2	0	-0,0005	-0,0006		-0,0006	-0,0011	+0.0004	+0.0007	-0.0002		
	B_1	0	-0,0004	-0,0008		-0,0007	-0,0014	+0.0005	+0.0006	0.0000		
	B_2	0	-0,0010	-0,0015		-0,0009	-0,0017	+0.0000	+0.0006	0.0000		
13-85	A_1	0	-0,0010	-0,0012		-0,0012	-0,0024	-0.0007	-0.0002	-0.0010		
	A_2	0	-0,0012	-0,0020		-0,0021	-0,0024	-0.0013	-0.0010	-0.0018		
	B_1	0	-0,0014	-0,0015		-0,0012	-0,0016	-0.0007	-0.0003	-0.0011		
	B_2	0	-0,0015	-0,0018		-0,0016	-0,0030	-0.0008	-0.0007	-0.0012		
VARIATION DE LONGUEUR DES BARREAUX DE 1" X 1" X 10" EXPRIMÉE EN %												
13-84	A_1	0	0	-0,008		-0,003	-0,012	+0.006	+0.005	+0.001		
	A_2	0	-0,005	-0,006		-0,006	-0,011	+0.004	+0.007	-0.002		
	B_1	0	-0,004	-0,008		-0,007	-0,014	+0.002	+0.006	0.000		
	B_2	0	-0,010	-0,015		-0,009	-0,017	+0.000	+0.006	0.000		
			-0.005	-0.009		-0.006	-0.014	+0.003	+0.007	0.000		
13-85	A_1	0	-0,010	-0,012		-0,012	-0,024	-0.007	-0.002	-0.010		
	A_2	0	-0,012	-0,020		-0,021	-0,024	-0.012	-0.010	-0.018		
	B_1	0	-0,014	-0,015		-0,012	-0,016	-0.007	-0.003	-0.011		
	B_2	0	-0,015	-0,018		-0,016	-0,030	-0.008	-0.007	-0.013		
			-0.013	-0.016		-0.015	-0.024	-0.008	-0.007	-0.013		

NOTES: + = gonflement
- = retrait

Lecture initiale le 3 avril 1985

3 months : 1985.07.03
4 months : 1985.08.03
6 months : 1985.10.03
9 months : 1986.01.03
12 months : 1986.04.03
18 months : 1986.10.03
24 months : 1987.04.03

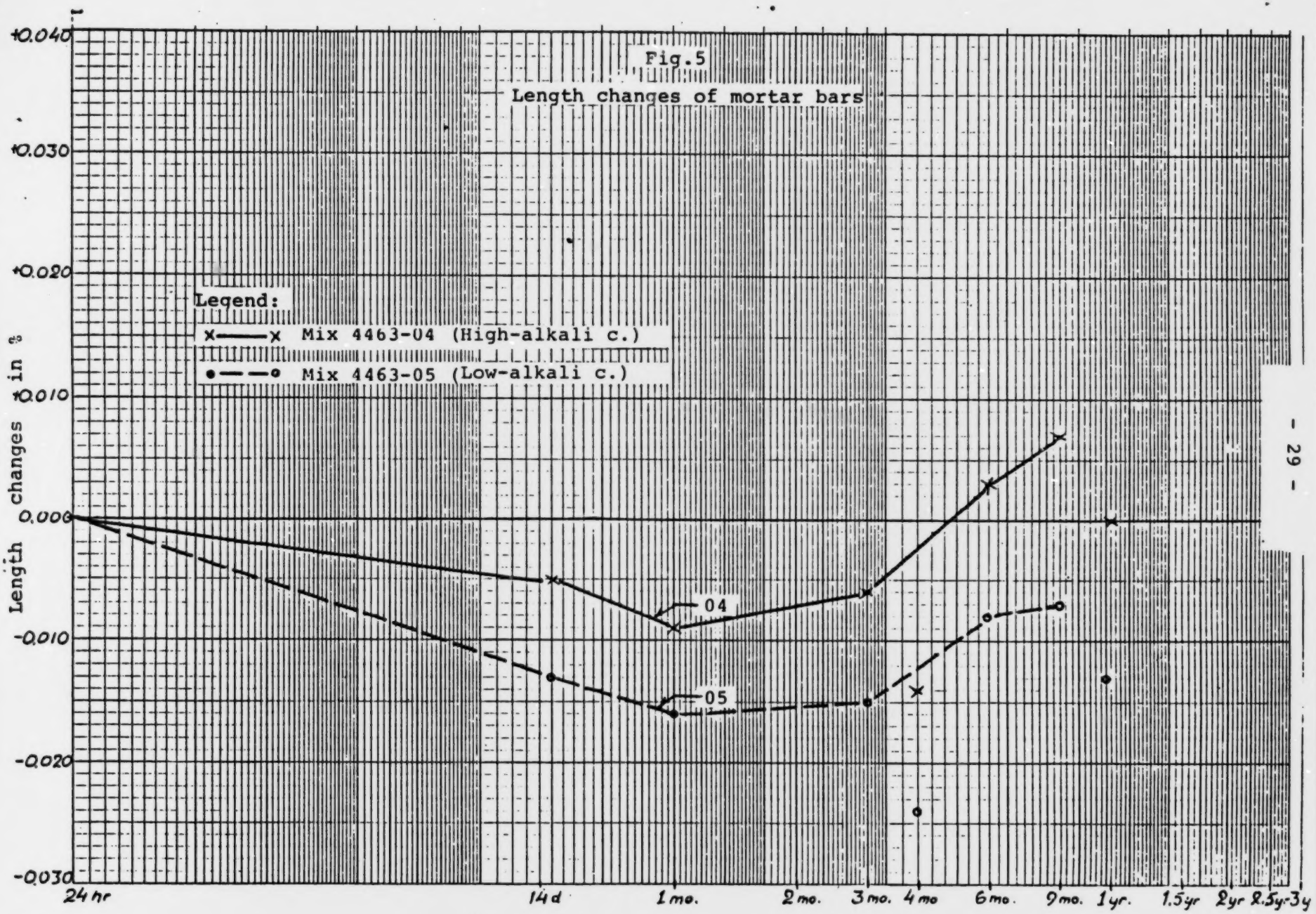


Fig.5
Length changes of mortar bars
Legend:
x——x Mix 4463-04 (High-alkali c.)
•— —o Mix 4463-05 (Low-alkali c.)
Length changes in %
+0.040
+0.030
+0.020
+0.010
0.000
-0.010
-0.020
-0.030
04
05
24 hr
14 d
1 mo.
2 mo.
3 mo.
4 mo
6 mo.
9 mo.
1 yr.
1.5 yr
2 yr
2.5 yr
3 y

4.2.6 Concrete prism tests - The concrete prism tests according to CSA Test Method A23.2 - 14A, Alkali - Aggregate Reaction, were made by the Laboratoire de Béton Ltée of Montreal.

Three concrete mixes, designated No.4463-06, -07 and -08, were made on March 26, 1985.

The coarse aggregate used was crushed rock from sample R-4A. It was washed and separeted in 3 equal portions:

a) 20 mm to 14 mm; b) 14 mm to 10 mm and c) 10 mm to 5 mm. The unit weight of dry-rodded coarse aggregate 20 mm to 5 mm size, was 1522 kg/m^3.

The fine aggregate used was mill-tailing sand sample S-8A with a grading as shown in Figure 1, having a F.M = 2.67.

As a reference sand, Francon sand from Joliette, Que., was used in the third concrete mix. Its grading is shown in Table 3.

Cements used were type 10: high-alkali cement from the Bath plant in Ontario and low-alkali cement from the St. Constant plant in Quebec. The alkali contents shown in Table 9, are 1.0% and 0.47%, respectively.

According to the CSA test method the concrete mix shall be proportioned to the following requirements:

Cement	310 ± 3 kg/m^3
Slump	80 ± 10 mm
Air content -	not to exceed 3%.

Composition and properties of concrete mixes No. 4463-06, 4463-07 and 4463-08 are shown in Tables 11, 12 and 13, respectively, using either high-alkali or low-alkali Type 10 cements.

The test specimens were 75 x 75 x 350-mm prisms with stainless steel studs cast in the centre of each end, providing a 320-mm effective gauge length. Three sets, each consisting of three test prisms were made in accordance with CSA Test Method A23.2 --14A requirements.

After 24 h in a moist curing room, the prisms were demoulded and immediately immersed in water at a temperature of 23 ± 2°C for 30 ± 5 min. The specimens were then measured for length. After initial measurements were taken the specimens were returned to the moist curing room for storage. Measurements of length changes were made after 7, 14, 28, 56, 84, 112 and 168 days of moist storage and every 6 months thereafter. The difference between initial measurement and each succeeding measurement, taken to the nearest 0.01 mm, were recorded for each prism and the average was calculated and expressed to the nearest 0.001% of effective gauge length. The data for each set of prisms are shown in Tables 14, 15 and 16.

The length changes in percentages for each set of prisms Nos. 4463-06, 4463-07 and 4463-08 are plotted on graphs in Fig.6. Graph "06" shows length changes for concrete test prisms made with high-alkali and graph "07" for prisms with low-alkali cement.Graph "08" represents langth changes for concrete made with high-alkali cement and sand from Joliette, Que. The 56-day measurements (gr.I) and 168-day meas. (gr.II) are inconsistent with the general trend of the graphs. The cause is unknown, but as the anomalous length changes do not appear related to normal shrinkage or expansion, the readings were not included in the graph plot.

Table 11

Composition and properties of concrete

Mix number 4463-06

(high-alkali cement)

Mix number	:	4463-06
Cement type	:	10 from Canada Cement Lafarge, Bath, Ontario alkalis 1,0%
Coarse Aggregate	:	Sample R4A
Fine Aggregate	:	Sample S8A

			BASIC MIX DESIGN	LABORATORY MIX RESULTS	CORRECTED BASIC MIX
Cement	kg	(1)	310	12,4	308
Coarse aggregate	kg	(2)	1000	40,0	994
Fine aggregate	kg	(3)	870	34,8	865
Water	kg	(4)	185	8,54	212
Total	kg	(5)	2365	95,74	2379
W/C Ratio		(6)	0,60	0,689	0,69
Temperature of concrete	°C	(7)	-	21	-
Ambiant temperature	°C	(8)	-	20	-
Slump	mm	(9)	80±10	60	-
Air	%	(10)	<3,0	2,2	-
Unit weight	kg/m³	(11)	-	2379	-
Volume	m³	(12)	-	0,0402	1,00

Table 12

Composition and properties of concrete

Mix number 4463-07

(low-alkali cement)

Mix number	:	4463-07
Cement type	:	10 from Canada Cement Lafarge, St-Constant Québec, Alkalis 0.47%
Coarse Aggregate	:	Sample R4A
Fine Aggregate	:	Sample S8A

			BASIC MIX DESIGN	LABORATORY MIX RESULTS	CORRECTED BASIC MIX
Cement	kg	(1)		12,4	311
Coarse aggregate	kg	(2)	1000	40,0	1003
Fine aggregate	kg	(3)	870	34,8	873
Water	kg	(4)	185	8,53	214
Total	kg	(5)	2365	95,73	2401
W/C Ratio		(6)	0,60	0,688	0,69
Temperature of concrete	°C	(7)	-	20	-
Ambiant temperature	°C	(8)	-	19	-
Slump	mm	(9)	80±10	65	-
Air	%	(10)	<3,0	1,6	-
Unit weight	kg/m³	(11)	2365	2401	-
Volume	m³	(12)	-	0,0399	1,00

Table 13

Composition and properties of concrete

Mix number 4463-08

(high-alkali c. and Joliette sand)

Mix number : 4463-08

Cement type : 10 from Canada Cement Lafarge, Bath Ontario
Alkalis 1,0%

Coarse Aggregate : Sample R4A

Fine Aggregate : Sand from Joliette taken at Francon Plant

			BASIC MIX DESIGN	LABORATORY MIX RESULTS	CORRECTED BASIC MIX
Cement	kg	(1)	310	12,4	308
Coarse aggregate	kg	(2)	1000	40,0	993
Fine aggregate	kg	(3)	890	35,6	883
Water	kg	(4)	185	7,21	179
Total	kg	(5)	2385	95,21	2362
W/C Ratio		(6)	0,60	0,581	0,58
Temperature of concrete	°C	(7)	-	17	-
Ambiant temperature	°C	(8)	-	18	-
Slump	mm	(9)	80±10	95	-
Air	%	(10)	<3,0	2,5	-
Unit weight	kg/m³	(11)	-	2362	-
Volume	m³	(12)	-	0,0403	1,00

Table 14

LENGTH CHANGE RESULTS

CSA Test Method A23.2-14A.

Mix number : 4463-06

Cement type : 10, 1,0% alkalis

Coarse Aggregate : R-4A

Fine Aggregate : S-8A

EFFECTIVE LENGTH OF THE PRISM : 320 mm

DATE	AGE	CHANGE LENGTH IN mm and %				
		PRISM			AVERAGE	
		A mm	B mm	C mm	mm	%
85-03-28	24 hours	-	-	-	-	-
85-04-03	7 days	0	0	0	0	0
85-04-10	14 days	0	0	0	0	0
85-04-24	28 days	-0,02	-0,02	-0,02	-0,02	-0,006
85-05-22	56 days	-0,17	-0,15	-0,14	-0,15	-0,048
85-06-19	84 days	-0,08	-0,07	-0,07	-0,07	-0,022
85-07-17	112 days	-0,06	-0,06	-0,07	-0,06	-0,020
85-09-11	168 days	-0,04	-0,03	-0,03	-0,03	-0,011
85-12-27	9 months	-0,09	-0,07	-0,07	-0,08	-0,024
86-03-27	12 months	-0,07	-0,06	-0,06	-0,06	-0,020
86-09-26	18 months					
87-03-27	24 months					

Table 15

LENGTH CHANGE RESULTS

CSA Test Method A23.2-14A.

Mix number : 4463-07

Cement type : 10, 0.47% alkalis

Coarse Aggregate : R-4A

Fine Aggregate : S-8A

EFFECTIVE LENGTH OF THE PRISM : 320 mm

DATE	AGE	CHANGE LENGTH IN mm and %				
		PRISM			AVERAGE	
		A mm	B mm	C mm	mm	%
85-03-28	24 hours	-	-	-	-	-
85-04-03	7 days	0	0	0	0	0
85-04-10	14 days	0	0	0	0	0
85-04-24	28 days	-0,05	-0,05	-0,05	-0,05	-0,016
85-05-22	56 days	-0,12	-0,14	-0,15	-0,14	-0,043
85-06-19	84 days	-0,06	-0,08	-0,09	-0,08	-0,024
85-07-17	112 days	-0,05	-0,07	-0,07	-0,06	-0,020
85-09-11	168 days	-0,02	-0,03	-0,02	-0,02	-0,007
85-12-27	9 months	-0,06	-0,08	-0,08	-0,07	-0,022
86-03-27	12 months	-0,05	-0,07	-0,07	-0,06	-0,020
86-09-26	18 months					
87-03-27	24 months					

Table 16

LENGTH CHANGE RESULTS
CSA Test Method A23.2-14A.

Mix number : 4463-08

Cement type : 10, 1,0% alkalis

Coarse Aggregate : R-4A

Fine Aggregate : Sand from Joliette (Francon)

EFFECTIVE LENGTH OF THE PRISM : 320 mm

DATE	AGE	CHANGE LENGTH IN mm and %				
		PRISM			AVERAGE	
		A mm	B mm	C mm	mm	%
85-03-28	24 hours	-	-	-	-	-
85-04-03	7 days	0	0	0	0	0
85-04-10	14 days	0	-0,01	0	0	0
85-04-24	28 days	-0,04	-0,05	-0.03	-0,04	-0,012
85-05-22	56 days	-0,15	-0,16	-0,15	-0,15	-0,047
85-06-19	84 days	-0,07	-0,08	-0,07	-0,07	-0,023
85-07-17	112 days	-0,06	-0,07	-0,08	-0,07	-0,022
85-09-11	168 days	-0,01	-0,02	-0,03	-0,02	-0,006
85-12-27	9 months	-0,07	-0,08	-0,08	-0,08	-0,024
86-03-27	12 months	-0,05	-0,07	-0,07	-0,06	-0,020
86-09-26	18 months					
87-03-27	24 months					

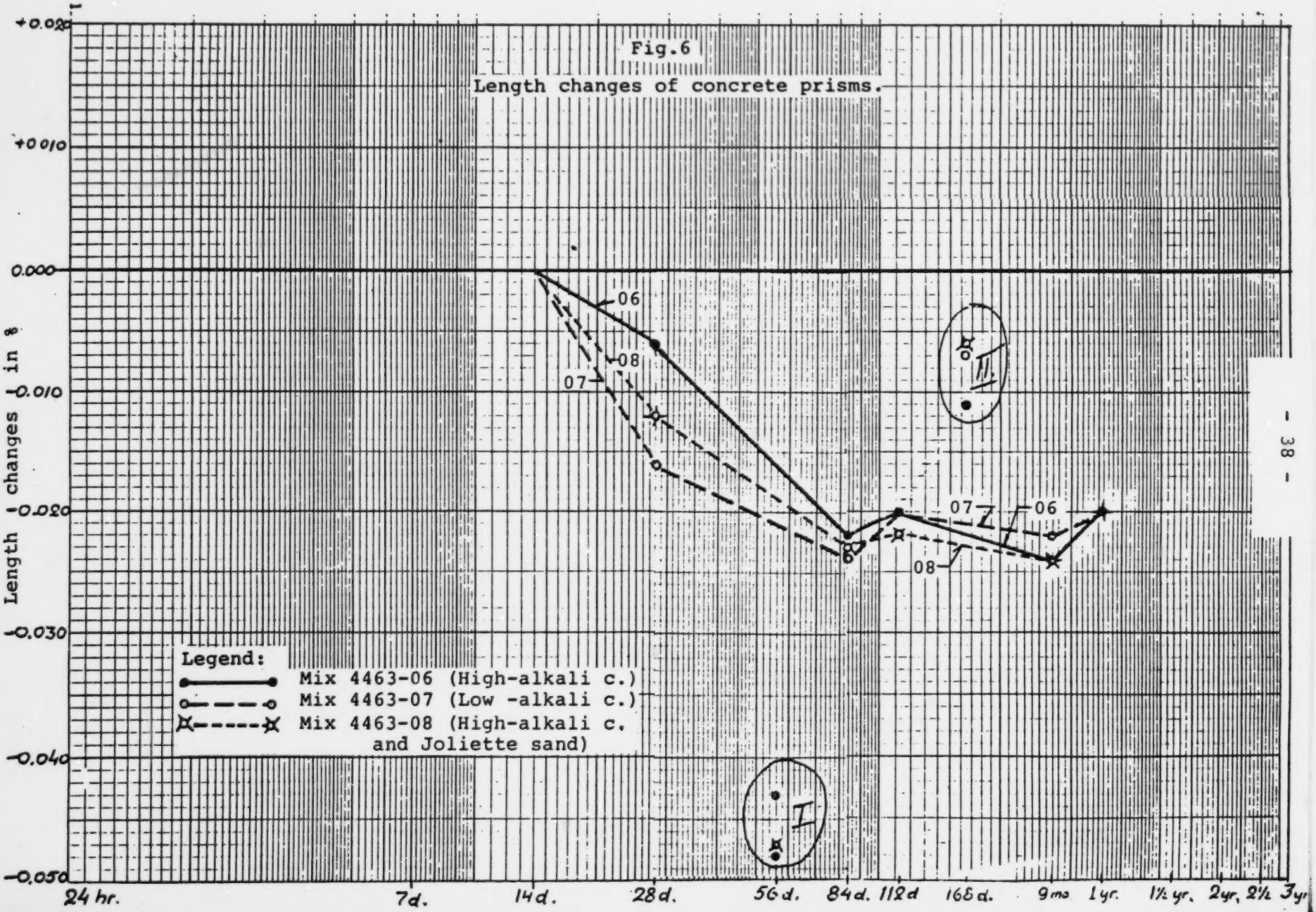


Fig.6
Length changes of concrete prisms.
+0.020
+0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
Length changes in %
06
08
07
II
07
06
08
I
Legend:
Mix 4463-06 (High-alkali c.)
Mix 4463-07 (Low -alkali c.)
Mix 4463-08 (High-alkali c. and Joliette sand)
24 hr.
7d.
14d.
28d.
56d.
84d.
112d
168d.
9mo
1yr.
1½ yr.
2yr.
2½
3yr

In addition to the set of 3 prisms, two 150 x 300-mm test cylinders were made from each concrete batch for testing in compression at 28 days. The test results are shown in Table 17.

Note that the compressive strength of concrete mixes Nos. 4463-06 and -07 are only 82% and 87%, respectively, as compared with mix 4463-08, which was made with Joliette sand. Concrete mix data given in Tables 11, 12 and 13 indicate that less water was used for the concrete mix made with Joliette sand, resulting in a water cement ratio W/C= 0.58 and a slump of 95 mm, compared with W/C = 0.70 and slump of 60 and 65 mm for the two other mixes in which test sand S-8A was used.

The sieve analyses in Table 3 show that the amount of material finer than 80 μm in sand sample S-8A was 5.4%, whereas the Joliette sand contained only 0.6%. The greater amount of fines would increase the water requirement and raised the W/C ratio, which would lower the strenth of concrete significantly

Table 17

CONCRETE MIX CHARACTERISTICS AND COMPRESSIVE STRENGTH

(CSA TEST METHOD CAN3 A23.2-9C)

MIX NO	CEMENT TYPE	AGGREGATE		WATER CEMENT RATIO	CONCRETE MIX		STRENGTH IN MPa		
		COARSE	FINE		SLUMP (mm)	AIR %	28 days	Average MPa	Rate in %
4463-06	10 1.0% alkalis	R-4A	S-8A	0.689	60	2.2	20.0 20.5	20.25	82
4463-07	10 0.47% alkalis	R-4A	S-8A	0.688	65	1.6	21.5 21.7	21.60	87
4463-08	10 1.0% alkalis	R-4A	Sand from Joliette Que.	0.581	95	2.5	24.6 24.9	24.75	100

5. DISCUSSION OF TEST RESULTS

Information provided by the recent petrographic examination indicates that no poor or deleterious constituents are present in the aggregate under investigation.

The ASTM C 289 chemical test showed that these aggregates should not be considered potentially alkali-reactive; they would be defined as innocuous. To determine if this were so, mortar bar and concrete prism expansion tests were made, using both high- and low-alkali portland cements.

The tests showed that the mortar bars expanded less than the concrete prisms. In both, expansion was preceded by initial shrinkage. For mortar bars made with high-alkali cement (Graph 04) the maximum shrinkage was -0.009% at 1 month, which reversed to gradual expansion at later ages; the net expansion at 9 months was +0.007%. For mortar bars with low-alkali cement (Graph 05) the initial shrinkage reached -0.016% at 1 month, which gradually reduced to -0.007% at 9 months. Thus, total expansion values in 9 months were 0.016 and 0.009%, respectively, for high- and low-alkali cement mortar bars. These values are well below the expansion limits set for the ASTM C 227 mortar bar test (0.05% at 3 months or 0.10% at 6 months).

The concrete prisms had much greater shrinkage than the mortar bars. The initial shrinkage for all three sets of prisms reached about -0.023% after 84 days of moist curing; this reduced to about -0.020% at 112 days, where it stayed for the rest of the year. The expansion of prisms within 1 year is too low to compensate for shrinkage that occured during the initial 84-day period.

Thus, the total expansion values for concrete prisms in 1 year were 0.002 to 0.004%, well below the limit set by CSA A23.1- M77, Appendix B3.5, which is 0.03% at any age. It is specified as 0.02% in 3 months for field structures exposed to moist environments and 0.04% for those exposed to dry conditions.

The upward trend of the mortar bar graph, as well as the tail end of the concrete prism graph, may indicate the presence of late-expansive material. These test specimens should be investigated further by keeping them under present curing conditions for another 2 years for measurements at later ages.

6. C O N C L U S I O N S

The preliminary petrographic examination and chemical tests did not indicate that any potentially harmful alkali reactive minerals were present in the waste rock and mill tailing sand from Hilton Mines, at Shawville, Que.

The mortar bar and concrete prism test results show that considerable shrinkage takes place at early ages, which is partly compensated by some expansion during the first year of testing.

One year testing is not sufficient time, however, to establish whether some late-expansive reaction could occur that would ultimately be harmful to the concrete. Therefore, it is recommended that length measurements on the test specimens, both concrete prisms and mortar bars, be continued for another 2 years.

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7. REFERENCES

1. James A. Soles, "Petrographic studies of potential concrete aggregate: Waste rock from Marmoraton and Hilton Mines", MRP/MSL 76-67, March 1976.
2. George G. Carette, "Evaluation of waste rock from Hilton Iron Mines as a concrete aggregate", MRP/MSL 77-281, Sept. 1977.
3. Nikolai G. Zoldners, "Durability testing of a prestressed concrete tie (CONTIE no.25)". Tests made and report prepared for the Lamarche McGuinty Inc., Shawville, Que.,Jan. 1983.

8. APPENDICES*

A. Petrographic analyses.

Report by Dr. Jean Bérard, Geologist, Ecole Polytechnique of Montreal - on 10 samples of crushed stone and 10 samples of manufactured sand (mill tailings).

B. Chemical tests - ASTM C 289.

Report by V. Kubat, resp. Laboratoire de Géochimie Analytique, Ecole Polytechnique, Université de Montreal, Que.

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* Copies available from Dr. J.A. Soles,
CANMET Scientific Authority for the project.